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ABSTRACT

Geophysics is the application of physics, chemistry, and mathematics to the problems and processes of the earth, from its innermost core to its outermost environs in space. Fields within geophysics include the atmospheric sciences; geodesy; geomagnetism and paleomagnetism; hydrology; oceanography; planetology; seismology; solar-planetary relationships; tectonophysics; and volcanology, geochemistry, and petrology. This booklet, designed to serve as an introduction to geophysics for high school students, provides descriptions of each of the fields as well as brief comments on careers in geophysics. (JN)

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Geophysics

the Earth in Space

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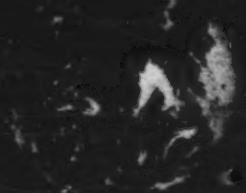

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Introduction

A new generation of geophysical scientists and engineers is needed both to perform basic research in the earth and space sciences and to apply that knowledge to the solution of human problems. This booklet is designed to serve as an introduction to geophysics for high school students and seeks to answer such questions as:

- What is the science of geophysics?
- What do geophysicists do?
- How should I prepare myself for the study of one or more areas of geophysics?

More specific information on preparing at the undergraduate level for a career in geophysics can be found in AGU's college-level career booklet *Careers in Geophysics*, single copies of which are available free of charge.

Geophysics— The Earth in Space

Geophysics is the application of physics, chemistry, and mathematics to the problems and processes of the earth from its innermost core to its outermost environs in space. There are solid-earth areas such as: seismology, volcanology, geochemistry, petrology, tectonophysics, geomagnetism and geodesy, and fluid-earth areas covered by oceanography, meteorology and hydrology. The upper atmosphere, the ionosphere, the radiation belts, the earth's magnetic field in space, the magnetosphere, solar-planetary relationships, the sun, interplanetary space, and the physics and chemistry of other planets constitute other areas of interest to geophysicists.

The solid-earth studies include the investigation of earthquake waves that, traveling through the earth, give clues to the internal structure and composition of our planet. Studies of methods for predicting earthquakes now being undertaken may lead to the saving of many lives and to a reduction in damage. Paleomagnetism and heat flow studies have yielded evidence pointing to the possible motion of continents and sea floor from earliest times to the present. Studies of the moon and planets are improving our understanding of the origin of the earth and of the solar system.

The ocean is a vast frontier containing great untapped reservoirs of resources. It is important that we understand the movements of ocean waters and their chemistry, and the interactions at the ocean bottom, at the air surface, and with bordering land areas.

The waters of the land, studied by hydrologists, are important to every city and rural business and individual from the standpoint of water supply, floods, pollution, water power, inland waterway transportation and many other aspects.

The forecasting of weather requires a deep understanding of meteorology, the physics of the atmosphere. Intensive studies are underway of this relatively thin layer of air in which we live and breathe. Atmospheric pollution problems can only be solved by understanding the chemistry and movement of the air. Uneven heating, the rotation of the earth, the cold polar regions, and mountain ranges are a few of the factors that influence the atmosphere's dynamics.

Conditions in the upper part of the atmosphere affect radio and television communication, therefore an understanding of the ionosphere, and the magnetic field of the earth in space, is very important. The conditions of these regions are directly related to the behavior of the sun. Great solar flares extending as much as a half million miles above the surface of the sun have important effects upon the highly rarefied atmosphere within the magnetosphere and in interplanetary space.

The study of geophysical problems depends on a good foundation in physics, mathematics and chemistry. Most geophysicists major in one of these fields in their undergraduate program and specialize in geophysics only upon entering graduate school. Geology is basic to solid-earth geophysics and planetology and therefore is a useful minor.

The American Geophysical Union draws together scientists in all of the disciplines that treat the study of the earth in its environment in space. It is divided into ten sections, each covering an important area of research. A brief description of these areas follows.

Atmospheric Sciences

During the past two decades advances in the theory of atmospheric motions, the development of earth satellites, and continued improvements in high-speed digital computers have brought man closer to realizing his ancient desire to understand and influence the atmosphere.

Worldwide data are used routinely to make mathematical predictions of the state of the atmosphere. Forecasts are now limited to a few days, but, as analysis of earth satellite

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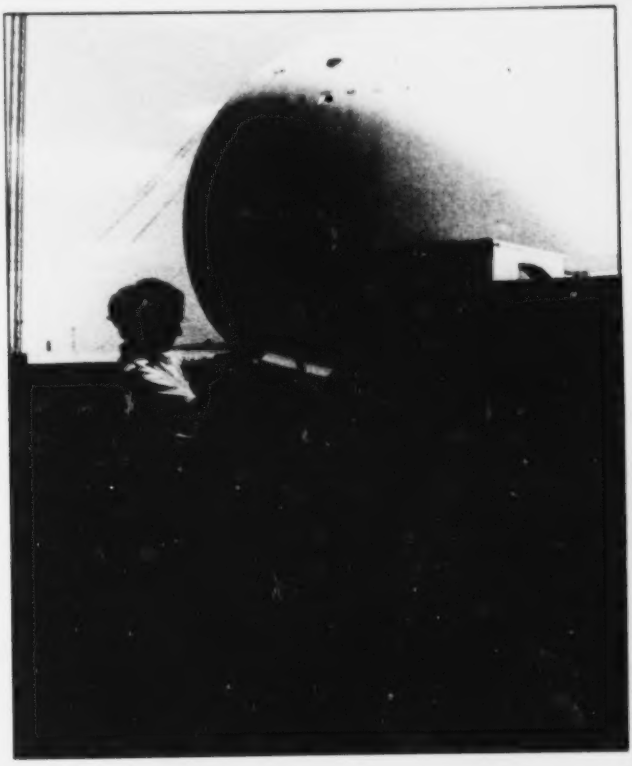
Atmospheric scientists Vin Toutenhoofd (foreground) and Ted Cannon preparing to take off for a high altitude glider flight



NCAR photo

Convective storm research equipment in Grover, Colorado

observations become more refined and computer speed and capacity are increased, new mathematical models will be applied, extending forecasts to longer periods. Similar methods will be used to examine means for modifying weather and climate, pinpointing which are most effective and whether active experiments might cause major undesirable effects.

Atmospheric scientists are also investigating the high atmosphere by rocket, radio, and optical methods, doing laboratory and field research into the physics of clouds, rain, snow, and thunderstorms; studying behavior of small particles and contaminants; developing new sensors and methods of measuring, transmitting, and recording data; and considering the interaction of the ocean and atmosphere, the effect of land surface on the atmosphere; the atmospheres of the sun and other planets; and biological effects of weather and climate.

These professionally trained scientists find rewarding careers in industry, government, education, and research in the fields of space technology, air transportation, communications, air-pollution control and abatement, agriculture, and

weather forecasting and modification. Many of these activities are international, and provide opportunities for strengthening understanding and cooperation among nations.

Undergraduate meteorology students normally study general physics and calculus during their first two years. Most meteorology courses are taken in the last two years. Baccalaureate degrees prepare students for professional careers in government and industry. Graduate studies increase career opportunities greatly, and meteorology graduate programs accept students with bachelors' degrees in all areas of science and engineering.

Geodesy

Geodesy is the study of the size, shape, and gravitational field of the earth. One of its most important tasks is to make measurements and computations necessary for accurate mapping of the earth's surface. With man's conquest of space this task extends to celestial bodies other than the earth.

Networks of observation points are set up, and their positions on the earth's surface are determined very precisely. Networks of precisely determined elevations above mean sea level are also established. These networks serve as bases for further measurements from which accurate maps can be drawn.

From measurements and study of the earth's gravitational field, we have learned that the pull of gravity varies from place to place. For example, the field is greater at the poles than it is at the equator. These observations combined with observations of the geodetic satellites lead to the definite determination of the general shape of the earth. Gravitational studies give us an insight into the internal constitution of the earth's crust, and are an aid in oil exploration and in the surveying for natural resources such as iron ore, natural gas, and salt. These results have economic as well as scientific interest.

Geodesists talk in terms of triangulation (measurement of angles), trilateration (measurement of lengths), leveling (measurement of heights above sea level), and gravimetric surveys (measurement of the pull of gravity). Distances can now be measured by electronic means with great accuracy and speed by measuring very accurately the time necessary for light or other electromagnetic waves to pass from one point to another and back. Satellites especially designed for geodetic purposes provide means of accurately finding the directions and distances between points, which may be on different continents and separated by ocean areas.

Pole motion, pole wandering, the movement of continents relative to one another and Earth tides are also studied.

U.S. Dept of the Interior GEOLOGICAL SURVEY

Scientist surveys the land to look for changes in the shape of the earth

Mathematics and physics provide the background of geodesy, but other disciplines are involved. Astronomy is used in terrestrial as well as satellite measurements.

Several universities in the United States offer courses in geodesy. Some are on the undergraduate level, others on the postgraduate level. Broad operational and research opportunities are available in the field of geodesy in government, academic and industrial organizations.

Geomagnetism and Paleomagnetism

Although the study of the geomagnetic field is one of the oldest scientific disciplines, we have only crude answers to most of the questions posed by this phenomenon. The earth's magnetic field, although originating deep within the earth, extends far into space. It interacts both with magnetic minerals of different rocks and with the solar and planetary magnetic fields, creating the magnetosphere which extends to far out in space.

The measurement and study of these interactions, spatially varying in the case of mineral deposits or changing geological structure and time varying in the case of external interactions, require the efforts of many earth scientists. The magnetic properties of some kinds of rocks have also yielded a vast amount of information about the past magnetic fields of the earth to a rapidly growing number of scientists—paleomagnetists. This is because the magnetism of these rocks (e.g., a lava flow) was acquired at the time they solidified and formed a record of the magnetic field at that time. By properly studying this "fossil" magnetism, much is being learned about the ancient fields; moreover, the ancient field and its changes are having great importance in hypotheses of ocean-floor spreading, continental drift, and polar wandering: the new theory of plate tectonics.

In the space around the earth, the magnetic field of the earth controls the motion of solar electrons and protons which enter the earth's environment. Some of these particles become trapped in the Van Allen radiation belt; others move down the field lines into the lower ionosphere where they collide with the molecules of atmospheric gases, which become ionized and energized. The ionization disrupts communication systems, and the excitation results in light emissions, the most prominent of which are those of the aurora.

The geomagnetic field also controls the motion of electrons and ions found in the normal ionosphere, formed through ionization of the atmosphere by solar X-rays and ultraviolet emissions. The earth's magnetic field thus takes its student into many other disciplines, both academically and commercially, offering varied interests to those who pursue its study.

Accurate measurement of the earth's magnetic field continues at a network of geomagnetic stations first established in 1882. At intervals, more detailed surveys are made, updating and making more accurate the former observations. Accurate instrumentation is essential.

Hydrology

The study of the occurrence, behavior, and disposition of water in all its forms on and in the land areas of the Earth is hydrology. It is closely related to meteorology because the chief source of water is the atmosphere. Hydrologic problems are of great importance to us because water resources are becoming increasingly critical all over the world.

The great practical importance of water has sometimes outweighed a considered academic study of the problems. At the present time our total national expenditure on water resources development is more than 10 billion dollars yearly. To understand better the problems of our water resources, many university courses on the graduate and undergraduate

levels have been established. With an improved knowledge of hydrology, the money allocated for water resources may be more effectively employed.

Applications of hydrology are important to hydraulic engineering, agricultural engineering, agronomy and soil science, geology, chemistry, forestry, range management, biology, public health and energy development. To understand the resources available, the hydrologist must measure the rivers and streams, survey underground supplies of water and their movement, and must study the precipitation and infiltration rates.

Hydrologists also investigate glaciers, ice, snow, and permafrost, and develop principles of erosion and the movement and deposition of sediment. The hydrologist carries out studies in mountain regions and deserts, in forests and agricultural areas, in cities and on the university campus. He or she needs a strong background in mathematics, physics, and chemistry, and some knowledge of geology and biology.

In 1964 the Federal Government passed a law to establish a water resources research institute in each state. On the international scene, UNESCO, the World Meteorological Organization, and the International Association of Hydrological Sciences sponsor cooperative programs that have substantial value in assessing the world's water supply and in solving water problems.

The fields frequently recognized in this branch of geophysics are as follows:

- Precipitation
- Surface water
- Infiltration and percolation
- Evaporation and transpiration
- Chemistry of natural waters
- Chemistry of polluted waters
- Ground water
- Soil moisture
- Dynamics of streams
- Transportation and disposition of sediment
- Lakes
- Snow, ice and glaciers
- Permafrost
- Water resources systems

The opportunities in hydrology and water resources will continue to grow during the next decade.

Oceanography

Oceanography is the scientific study of the oceans, seas, estuaries, and large lakes on our planet, which, as far as is known, is the only planet with water oceans. An oceanographer applies the knowledge gained in physics, chemistry, biology, engineering, and mathematics to the scientific study of the oceans, and can specialize in one of five major areas: physical oceanography, marine meteorology (sea-air interaction), marine geophysics and geology (including sea-floor spreading), marine chemistry (all parts of geophysics), and marine biology (a part of the life sciences).

A study of the oceans is largely carried out from the specially designed ships and deep submersibles, fixed platforms in relatively shallow water, underwater laboratories inhabited by divers, and from aircraft and earth-orbiting satellites, both manned and unmanned. An ever-expanding number of instruments are used to sense and measure the properties of the oceans, the air above, and the sea-floor below.

Oceanography requires people trained at many different levels. Technicians are increasingly in demand, some vocational schools offer training in this area.

The college-bound student has two options. Either he can major in a single basic science such as physics, mathematics, zoology, or chemistry, being sure to become well-grounded in the related areas of science, and then study the oceans as a graduate student; or he can major in some area of the ocean sciences at the undergraduate level, then continuing his training in oceanography, and the related sciences and mathematics at the graduate level. Oceanography is expanding rapidly, and there is a great demand for workers in all areas.

NOAA photo

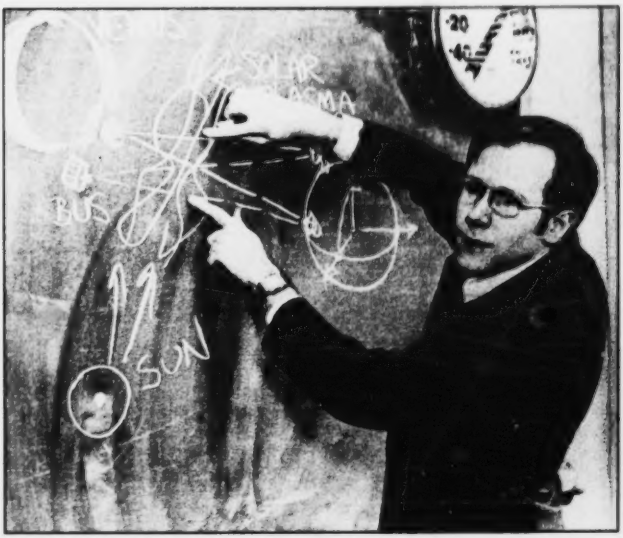
Oceanographer Bonnie McGregor Stubblefield and cartographer Sue O'Brien.

Planetology

Planetology is the study of the moon, the other planets, and other massive bodies in the solar system. How do they resemble, and how not, the earth? Answers to these questions will help us to understand the origin, history and structure of the earth. Do these other bodies have cores? Why does Venus have such a heavy, ever-cloudy atmosphere while Mars has so little? What is the origin of the craters and the rilles of the moon?

Why is the Martian landscape much like that of the moon, but with evidence of water flow? Why do some of the moons of Jupiter have a retrograde motion (revolving in an opposite direction from most of the solar system's moons)? Why is it that Mars, Venus and the moon have no or only small magnetic fields, but Jupiter's is very strong? Jupiter also sends forth strong radio emissions. What is the nature and origin of the asteroids in the space between Mars and Jupiter? Are these the remains of a disintegrated planet?

The answers to these questions and many others, the full meaning of which we cannot comprehend, depend upon the findings of deep space probes with astronauts or with geophysical instruments. These studies hold much for our greater understanding of our own planet, just like Columbus' journeys across the seas opened up new vistas with regard to other continents of the earth.



MIT photo

Charles Counselman, associate professor of Earth and Planetary Science at MIT, helped design tracking system for Venus Space Mission

Seismology

Seismology is the study of earthquakes, both natural and man-made. Most of what we known about the deep interior of the earth has been learned by seismologists studying the behavior of waves from large earthquakes. From small man-made explosions, information about the outer layers of the earth is obtained; this information can be used to aid in locating mineral and oil deposits. By means of small explosions in the ocean, we study not only the depth of the ocean waters, but also the structure of the layers below the ocean floor. Marine seismology has become increasingly important with the recent emphasis on the study of the oceans.

Natural earthquakes have caused many deaths and resulted in crippling damage to large areas since the beginning of mankind. One of the goals of seismology is to understand the causes of earthquakes sufficiently to predict their occurrence. A thorough knowledge of the seismicity, earthquake activity, of an area can be a guide to the design and building of structures that could withstand large earth tremors.

The distribution of earthquakes around the earth is far from random. About 30,000 earthquakes that occurred between 1961 and 1967 have been located by the U.S. Geological Survey. The earthquake locations from a number of belts around the earth, and the detailed study of their distribution and local mechanisms, have played a key role in establishing the theory of sea-floor spreading and continental drift, revolutionizing the fields of geology and solid-earth geophysics. Today, seismology is an exciting and rapidly-expanding science which is certain to continue in the forefront of the

U.S. Dept of the Interior GEOLOGICAL SURVEY

Waverly J. Person points to earthquake recorded at the National Earthquake Information Center in Golden, Colorado

study of the earth. Seismology is also playing an important part in our studies of the moon.

Most seismologic programs require a baccalaureate degree; a thorough foundation in mathematics, physics, and geology is necessary, as well as some knowledge of chemistry. If one wants to become a specialist in seismological exploration for oil, courses in geophysical engineering on the methods of seismic surveying are helpful. Several leading schools offer both graduate and undergraduate work in seismology. The fields of interest in seismology may be approximately listed as follows:

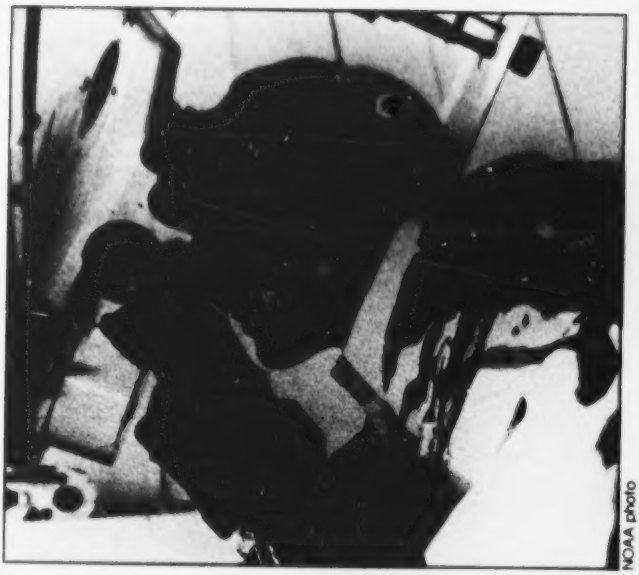
- Problems of earthquakes
- Transmission of vibratory waves through the Earth
- Seismic exploration
- Oceanographic seismology
- Internal constitution of the Earth
- Surface structure of the Earth
- Detection of nuclear explosions by seismic waves
- Relation between seismology and geology, particularly tectonics

There is a continuing need for workers in this field.

Solar-Planetary Relationships

The sun sends out not only its warming rays and visible light, but also a far wider range of radio, infrared, ultraviolet, X-ray and energetic particle radiations. Most of this broad spectrum is absorbed at high altitudes in the earth's atmosphere to produce complicated solar-terrestrial interactions.

By means of radio beams from the earth's surface, and by instruments on satellites and deep space probes, we investigate these phenomena. We make spectroscopic analyses of air glow, detect variations in the magnetic field, study the behavior of elementary particles of the Van Allen radiation belt, examine the full spectrum of solar electromagnetic waves and particles of the solar wind, and study the interplanetary environment and the magnetic field of the sun. These studies have discovered the magnetosphere which results from the interaction of the solar wind and the earth's magnetic field. The auroras are a visible manifestation of these interactions.



NOAA photo

Solar observer Lt. Mark Losleben of NOAA

Similar phenomena have been discovered at each of the planets and continue to be studied there, but each planet has its own peculiarities. The study of the upper atmosphere and its ionized part, the ionosphere, is called aeronomy. The study of the magnetic cavity carved out of the solar wind by magnetic fields of Mercury, the Earth, Jupiter and Saturn is called magnetospheric physics. Solar physics and interplanetary physicists also work on these problems. Often these scientists characterize themselves as space plasma physicists, for the primary medium they study is the fully ionized space plasma.

The past twenty years of solar-planetary research have been full of discovery. Future research will be characterized by diagnostic experiments aimed at understanding the basic physical processes. However, there may still be many exciting discoveries left in the study of cometary magnetospheres and with exploration of the distant planets. Further, the space shuttle is opening a new era of active experimentation in space plasmas.

Tectonophysics

Tectonophysics is the study of the earth's crust, including the forces that are at work and the properties of crustal materials. It involves the hypotheses and theories of sea-floor spreading, continental drift, down-warping in the trenches adjacent to island arcs, and the mechanism of earthquakes. What are the causes of the great faults such as the San Andreas fault in California? The ultimate goal of the tectonophysicist is to understand the earth's deformations in order to answer such problems.

Tectonophysics seeks to narrow the uncertainties about the earth and its behavior under the great forces and pressures that occur within it. What are the properties of the earth's material that permit elastic deformation or that bring about plastic flow or the internal movement that causes an earthquake? What are the great forces that cause these changes? It is necessary to study the physics of the earth's crustal material—its elastic properties, its thermal properties and the way it fractures. The study of heat flow from the interior of the earth outward is important. Tectonophysicists share these studies with volcanology, geochemistry, and petrology, and in the study of sea-floor spreading rely on the studies in paleomagnetism, seismology, and the deep-sea drilling project.

Thus, many of the problems are studied in cooperation with seismologists, volcanologists, solid-earth geochemists, petrologists, and structural geologists. Knowledge of geology, as well as a good foundation in mathematics and physics, is important in this field.

Advanced study in this field is available in all major departments where solid-earth geophysics is taught.

U.S. Dept of the Interior GEOLOGICAL SURVEY

Meyer Rubin and Beverly Masters, U.S. Geological Survey, Washington, D.C., at work in their carbon-14 dating lab

Volcanology, Geochemistry and Petrology

This group of sciences has become increasingly important in the last few decades. While it includes the study of volcanoes, it is also the study of the chemistry of the solar earth, the thermal structure of the earth's interior, and the processes that are involved. Ores are deposited, volcanoes erupt, rocks are formed. What forces are acting? What are the chemical changes? How much heat is produced in these changes?

Rocks as old as 3800 million years are known. What is the basis of this knowledge? How reliably can one determine such ages? How are rocks of this age distributed among the continents? The solution to these problems will provide the time scale of geological events—an important element in our understanding of the physical and chemical evolution of the earth.

What is the overall composition of the earth? What, for instance, are the most likely constituents of the earth's core?

U.S. Dept of the Interior GEOLOGICAL SURVEY

Cynthia Dusel-Bacon who lost her arms as a result of an accident continues to actively pursue her career studying rocks.

What are the laws governing the distribution of elements? What is the behavior of the chemistry and structure of materials when they are under great heat and great pressure such as one finds deep within the earth? Why do deposits of mercury develop in one place, deposits of tin in another, and why do they never occur together? What are the latest models of the temperature distribution within the earth, what are the limitations on the change of temperature with depth as one goes from the surface deeper and deeper toward the center of the earth? What can this temperature structure tell us of the information of oceans and continents?

Workers in these fields usually begin with an undergraduate degree in physics, chemistry or geology. The broader and more solid base in these subjects the better. Some knowledge of mathematics is essential. Post-graduate study is necessary in geochemistry, geology, solid-earth geophysics, and volcanology. The fields of study may be listed as follows:

- Origin of rocks
- Experimental petrology
- Geochronology
- Geochemistry
- Radiochemistry
- Volcanic activity and products
- Igneous and metamorphic petrology and mineralogy
- Isotopes and geochemical equilibria
- Geologic fluids
- Petrology

The demand for competent workers in these fields continues to be strong.

Careers in Geophysics

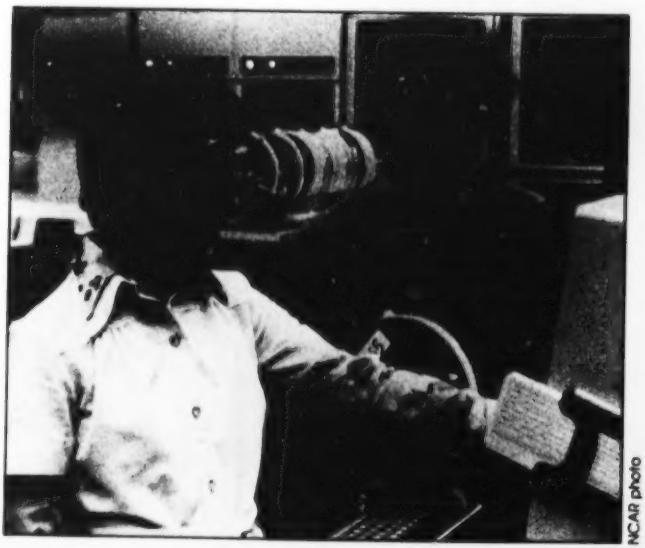
In all of these fields there are interesting and rewarding career opportunities at all levels of scientific and technological endeavor. Considering the current emphasis on environment, an increasing flow of students is needed in all aspects of geophysics.

Opportunities involve both field work and office work, frequently in combination, with a tendency toward more field work in the younger years.

Salaries are commensurate with those in other areas of science; beginning salaries vary with scholastic attainment and the type of work undertaken. Advancement depends largely on the ability and capacity of the individual—a challenge for one to do his or her best.

Information on salary scales and trends in various fields of science may be secured by writing to the Bureau of Labor Statistics, Department of Labor, Washington, D.C., or to the National Science Foundation, Washington, D.C. Government salary scales for various grades in the Civil Service may be secured from the U.S. Civil Service Commission, Washington, D.C.

June 1982



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Lofton Henderson and Joyce Takamine with a computer graphic readout.

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